

Air pollution continues to be a widespread human health and environmental problem in the United States. EPA's air quality program aims to ensure that the air in every American community is safe and healthy to breathe. In particular, children, the elderly, and people with respiratory illnesses need to be protected from health risks of breathing polluted air.

ORD's air research program provides the scientific foundation for EPA's air quality regulations, including the National Ambient Air Quality Standards (NAAQS) for particulate matter, ground-level ozone, carbon monoxide, sulfur dioxide, nitrogen oxides,

PARTICULATE MATTER

ORD's research program on particulate matter (PM) seeks to answer these key questions:

- *What characteristics of particulate matter (e.g., size, chemical composition) cause harm?*
- *What are the physiologic mechanisms by which particulate matter causes health problems?*
- *What is the role of particulate matter, alone and in combination with other pollutants, in producing health problems?*
- *What groups of people (e.g., asthmatics, children, elderly) are most sensitive to particulate matter and what are the critical levels of exposure for these groups?*

High-Priority Air Pollutants

and lead. The NAAQS undergo periodic review and are revised as justified by new information. ORD also conducts risk assessment and risk management research for substances designated as hazardous air pollutants, or air toxics. ORD's air research program includes clinical and laboratory research, community epidemiologic studies, and air quality model development and research. This chapter presents recent ORD accomplishments in research on particulate matter, air toxics, and air quality modeling.

- *What are the sources of particulate matter and how can we best estimate the fate of particulate matter in the atmosphere?*
- *What are the best strategies to control particulate matter air pollution?*

Based on particle size, particulate matter is categorized as ultrafine (0 to 0.1 micron in diameter), fine (0.1 to 2.5 microns), or coarse (2.5 to 10 microns). PM_{2.5} (particles less than 2.5 microns) and PM₁₀ (particles less than 10 microns) are older and less precise classifications that include all particles smaller than the specified diameter.

Cardiovascular Health Effects

To better understand the health problems related to particulate matter, ORD conducted a series of epidemiologic studies looking at the relationship between exposure to particulate matter and physiologic responses in sensitive populations such as the elderly, children, and asthmatics. For example, ORD researchers collaborated with scientists outside EPA to study the effects of ambient particulate matter on elderly residents of three retirement centers. Participants wore portable particulate matter monitors while multiple pollutants in outdoor and indoor air were measured. Several important findings emerged: the relationship between $PM_{2.5}$ and heart rate was consistent with findings from earlier studies; heart rate variability decreased at higher concentrations of $PM_{2.5}$; and respiratory function decreased with increasing $PM_{2.5}$ concentration, which could have been a reaction to ozone in addition to particulate matter.

Heart rate variability, which is controlled by the nervous system, is the ability of the heart rate to change in response to stress. Decreased heart rate variability has been identified as a risk factor for death from cardiovascular disease.

To further characterize the effects of particulate matter exposure on humans, ORD scientists conducted clinical studies in which volunteers in a controlled exposure chamber were exposed to concentrated particles collected from outdoor air. Healthy young adult participants (18 to 35 years old) experienced no symptoms of illness, no reduction in lung

function, and no change in heart rate variability after a total exposure of two hours, during which they exercised. However, when elderly participants (65 to 80 years old) were subjected to the same study conditions, they immediately experienced decreased heart rate variability, which persisted for many hours after exposure stopped. These findings are consistent with the studies conducted at retirement homes and suggest that



A participant being fitted with a portable particulate matter monitor.

particulate matter exposure influences nervous system control of heart rate in older people.

ORD also collaborated with academic scientists in several studies where rodents were exposed to particulate matter and other pollutants collected from outdoor air. Exposure to particulate matter was associated with reduced heart rate and an increased incidence of abnormal heart rhythms and death, especially among rodents with compromised heart or respiratory function. ORD is exploring the potential mechanisms responsible for these effects. Additional research is needed to confirm that the mechanisms in humans are similar to those in rodents.

Particulate Matter Research Centers

Through ORD's Science to Achieve Results (STAR) program, EPA established five Particulate Matter (PM) Research Centers to investigate the health effects of particulate

Locations of EPA's Particulate Matter Research Centers

Harvard University (MA)
University of Rochester (NY)
University of California at Los Angeles (CA)
New York University (NY)
University of Washington (WA)



matter. University scientists are working with ORD to characterize the relationship between ambient particulate matter levels and actual personal exposures, identify the toxic components of particulate matter and their associated biological effects, investigate the amount and distribution of particulate matter deposited in the respiratory tract, and identify groups of people that are particularly susceptible to the adverse effects of particulate matter. Highlights from the first two years of research follow.

- *Inhalation of particulate matter at concentrations only slightly above peak ambient levels can cause airway inflammation, which can lead to other physiological responses, such as thickening of the blood.*
- *Technologies were developed to collect and concentrate particulate matter in a controlled exposure chamber to examine how these pollutants affect cardiac and pulmonary function.*

- *Controlled exposure studies in humans and animals have shown associations between ultrafine particle exposures and changes in heart rate, heart rate variability, abnormal heart rhythms, and other heart and blood characteristics.*
- *Asthmatics may be particularly sensitive to ultrafine particles because these particles tend to be deposited in central airways of the respiratory system.*
- *In a study of healthy senior citizens, outdoor PM_{2.5} concentrations were significantly correlated with an individual's personal exposure to PM_{2.5}.*
- *An epidemiologic study found significant associations between mortality and exposure to particulate matter from traffic and coal-combustion sources, but not between mortality and exposure to particulate matter from oil combustion or soil.*

Particulate Matter Supersites Program

Through EPA's Particulate Matter (PM) Supersites Program, air quality research projects are being conducted at eight locations around the country. The program has three major objectives: characterize the chemical and physical properties of atmospheric particulate matter, provide data to support health and exposure studies, and evaluate new and existing methods for measuring particulate matter. Scientists from ORD and EPA's Office of Air and Radiation are leading this multidisciplinary research program.

Results from the PM Supersites Program will significantly improve our understanding of particulate matter formation and accumulation in the atmosphere throughout the United States.

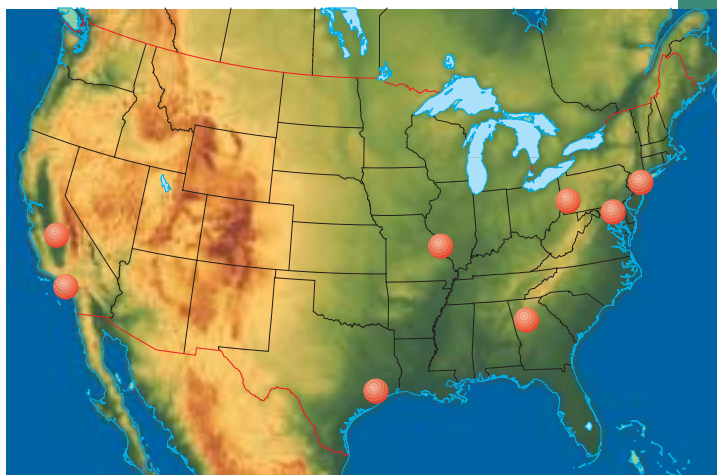
Phase I of the Supersites Program was initiated in 1999. Scientists in Atlanta, Georgia and Fresno, California evaluated the performance characteristics of various air quality monitoring methods and their suitability for use in state air quality monitoring programs and in later phases of the Supersites Program. To exploit the information collected through the Supersites Program, a data archive was established with the North American Research



Air monitoring equipment used in EPA's PM Supersites Program.

Strategy for Tropospheric Ozone (NARSTO).

The Atlanta data have been submitted to NARSTO and will be available to the public on the world wide web. The Atlanta study produced 35 peer-reviewed papers. A special subsection in the Journal of Geophysical Research-Atmospheres will include 22 papers submitted from the Supersites Program.



Locations of PM Supersites projects.

Phase II of the Supersites Program consists of projects in seven locations in the United States that have different atmospheric and meteorologic conditions and different sources of air pollution. The first major Phase II accomplishment was an intensive monitoring effort in Houston, TX and surrounding areas. This was followed by an intensive monitoring effort in July 2001, when 34 independent studies and existing national monitoring networks in the eastern United States were coordinated to collect the most comprehensive set of air quality monitoring data ever obtained.

Characteristics of Particle Emissions

Local and regional air quality managers rely on air quality simulation models to develop air pollution control strategies. Source profiles, which identify the quantities of specific air pollutants emitted from individual sources, are important data used in these models. Current source profiles for particulate matter are primarily for PM₁₀ (coarse particulate matter). EPA and local/regional air quality managers need source profiles for fine particulate matter because complex mixtures of organic compounds, many of which cause cancer and genetic mutations, make up approximately 30 to 50% of the fine particulate matter in urban environments.

Accurate source profiles for smaller particle sizes can be achieved. ORD recently established an in-house facility capable of performing the exacting analyses needed to identify and quantify the organic compounds, major ions, elemental and organic carbon, and trace elements present in fine particulate matter. Also, ORD built a state-of-the-art sampling system that provides representative samples of fine particulate matter in ambient air.

AIR TOXICS

ORD's air toxics program includes research on the sources and environmental fate of air toxics. The research program also evaluates toxicity, human exposure levels, dose-response relationships for health problems, and ways to characterize and manage risks posed by air toxics. Recent accomplishments in the air toxics research program are highlighted.

Toxicological Reviews

Risk assessments, formal evaluations of the likelihood that a substance is a threat to human health and/or the environment, are used in developing EPA's regulatory policies. Conducting accurate risk assessments for air toxics requires knowledge of the health effects of toxic air pollutants, data on exposure to air toxics, and appropriate models to quantify risk estimates under various exposure scenarios. To support EPA risk assessments, ORD conducts toxicological reviews of hazardous air pollutants

and other toxic substances. In 2001, assessments of three chemicals listed as hazardous air pollutants under the Clean Air Act—hexachlorocyclopentadiene, methyl chloride, and quinoline—were completed. Many other hazardous air pollutants and chemicals emitted from motor vehicles are in various phases of assessment and review.

Concentration-Duration Dynamics

An ORD research team conducted several studies to determine how exposure concentration and duration influence the toxicity of air pollutants. The scientists identified several fundamental principles important to predicting the toxic effect of hazardous air pollutants (see sidebar). This area of research supports the risk assessment process by improving the ability to predict health problems following exposure to specific pollutants under various exposure conditions.

Principles important to predicting the health problems caused by hazardous air pollutants

- The sensitivity of the affected tissues tends to change over time (either increases or decreases), which influences the toxic effect observed.
- Concentration of exposure is more important than duration of exposure, except in situations where the sensitivity of the affected tissue changes over time.
- Understanding how specific exposure conditions influence the dose delivered to the affected tissue improves accuracy in predicting the toxic effect.
- Computer models that incorporate biological or physiological processes are powerful tools for extrapolating conclusions across exposure concentrations and durations and across species and age categories.
- Knowing the mechanism by which a substance causes toxicity improves the ability to predict how changing exposure conditions will affect the likelihood of health problems.
- Standard toxicity assays do not account for acute exposures that may occur during critical life stages when an individual is most sensitive to pollutants.

Emissions from Open Burning

Burning household waste in barrels has been implicated as a potential major source of dioxin and dioxin-like compounds. When EPA received numerous requests from state and local agencies for information on emissions from burn barrels, the Agency conducted studies to characterize those emissions.

In 1999, scientists from ORD and EPA's Office of Pesticides, Prevention, and Toxic Substances (OPPTS) reported results of a study that characterized burn barrel emissions as a function of waste composition, burn conditions, and other physical properties (e.g., degree of compaction and moisture content). They found that emissions varied widely even when burn tests were performed on wastes of essentially identical composition. The factors most likely to account for this variability were total chlorine content, bulk density of waste, and the combustion conditions and temperatures. Future studies will examine other potentially important open burning scenarios, such as agricultural burning and construction debris burning.

AIR QUALITY MODELING

Computer models present one approach to understanding air pollution problems at local, regional, and national scales. Air quality models are being used to predict the concentrations of specific pollutants in a location under various emission scenarios. Air quality models can also



Firefighters in a controlled burn training class.

be used to allocate the pollutants in a locale to specific emission sources. With this information, policy makers can design efficient and effective air pollution control strategies.

ORD scientists are improving EPA's air quality modeling methods and systems. The Models-3/Community Multiscale Air Quality (CMAQ) system was first released by EPA in 1998, and has been upgraded about once each year since then. Other ORD research is providing high-quality data for use in the Models-3/CMAQ system and other air quality models.

Models-3/CMAQ

Models-3/CMAQ combines Models-3, a flexible software framework, and CMAQ, an urban-to-regional-scale air quality model designed to assess multiple pollutants. The modeling system integrates emissions data

processing, weather data modeling, chemistry-transport models, and analyses of inputs and outputs. It can simultaneously simulate the transport and fate of multiple pollutants across large geographic areas. It was developed as a multiscale (local, regional, national) and multipollutant (ozone, fine particulates, acid and nutrient deposition) model for use by EPA and state regulatory agencies to support air pollution control planning. Results of performance evaluations for four pollutant-specific applications of the Models-3/CMAQ system follow.

EPA's Models-3/CMAQ is a multiscale, multipollutant modeling system used to support air quality planning and atmospheric research.

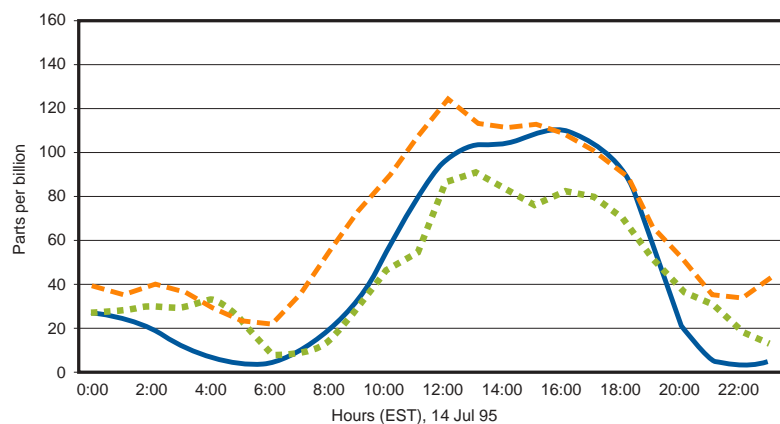
Performance Evaluation for Particulate Matter

To facilitate the use of Models-3/CMAQ, ORD is supporting collaborative model evaluations through agreements with several universities. In one Models-3/CMAQ evaluation, visibility was used as a surrogate for fine particulate matter (PM_{2.5}), an important air quality parameter for

which limited data exist. The evaluation compared observed visibility at 174 stations in the eastern half of the United States for a five-day period with visibility predictions generated by the model. The evaluation showed a general agreement between the modeled and observed values, suggesting the system is a useful tool for making risk management decisions.

Performance Evaluation for Ozone

The primary task of air quality models for ozone is to determine how limiting the emissions of ozone precursors—nitrogen oxides and volatile organic compounds—will reduce ground-level ozone concentrations. ORD scientists evaluated Models-3/CMAQ's predictive ability for ozone using data from two field studies. To better challenge the model, the scientists used data from a two-week period that included some of the highest and lowest daily ozone concentrations observed at approximately 560 monitoring sites in the eastern United States. Based on this initial evaluation, the



This graph shows that CMAQ (—) predicted the rise and fall in ozone levels observed at two monitoring stations (--- and ---) for one 24-hour period in the Washington, DC area.

After five years of development and testing, ORD recently introduced the Morphecules Method, a new computer model to simulate complex atmospheric chemistry processes. When scientists better understand the chemical processes that link the formation of ozone with the formation of fine particulates and air toxics, the Morphecules Method will enable resource managers to develop integrated pollution-control strategies addressing all important pollutants simultaneously.

model predicts high-ozone days quite well, but performs less satisfactorily on low-ozone days. It is worth noting that, while addressing multiple pollutants simultaneously, the model's performance is consistent with that of other models that simulate only ozone levels.

Performance Evaluation for Atrazine

ORD scientists expanded CMAQ to simulate how meteorologic factors interact to control the fate of semivolatile organic compounds, such as atrazine, dioxin, and dioxin-like compounds, over regional and local scales. Emissions of atrazine, a common agricultural herbicide, were modeled for a four-month period over the eastern United States. Comparing model results to observations showed that the model underpredicts atrazine deposited via precipitation while it overpredicts atrazine air concentrations. These findings imply that the model insufficiently accounts for the removal of airborne atrazine by rainfall and other forms of precipitation. ORD scientists are revising the model, with the goal of producing a CMAQ/atrazine model for public release in the near future.



Performance Evaluation for Mercury

ORD scientists developed the first version of a mercury module for CMAQ (CMAQ-Hg) in early 2000. Following a model comparison exercise sponsored by the European Monitoring and Evaluation Programme, the module was upgraded to better simulate the fate and transport of this toxic chemical. Still,

uncertainties exist regarding mercury chemistry in the atmosphere. By comparing model performance with measurements of mercury deposited at 11 sites across the eastern United States, ORD hopes to better understand the chemical processes that determine the fate of mercury in the atmosphere, and continue to refine the model.

Biogenic Emissions Inventory System

Biogenic emissions are compounds released from plants and other living organisms. In the presence of nitrogen oxides from manmade sources, biogenic emissions contribute to ground-level ozone formation. Therefore, accurate estimates of biogenic emissions are critical for assessing the regional-scale atmospheric processes that produce ground-level ozone and for formulating cost-effective pollution-control strategies.

Emitted mainly from forests, biogenic emissions are the largest single source of atmospheric volatile organic compounds in the United States.

The Biogenic Emissions Inventory System (BEIS) is a computer program that estimates emissions of volatile organic compounds from vegetation in large geographic areas. ORD scientists recently released a new version of the

Mercury Emissions

Mercury is a hazardous air pollutant, although atmospheric concentrations are usually low. However, when mercury particles fall from the air and end up in lakes, streams, and oceans, methylmercury—a toxic metabolite of mercury—can accumulate in fish and subsequently in fish-eating birds and mammals, including humans.



EPA has identified coal-fired utility boilers as the largest current source of atmospheric mercury emissions in the United States. In 2001, ORD published an interim report that included information on

- the legislative and regulatory background of EPA's recent decision to regulate mercury emissions from coal-fired electric generating stations;
- fuels, combustion technologies, and current pollution-control technologies for these stations;
- methods for measuring mercury at these stations;
- the forms of mercury produced when coal is burned; and
- new mercury and multipollutant control technologies that are under development.

program, BEIS3, which can produce emission estimates for use with EPA's Models-3/CMAQ system. Using model simulations and measurements taken in the field, ORD scientists confirmed high emissions of isoprene (one compound emitted from forests) from the Ozarks and the southeastern United States. This information will help determine how emissions of manmade nitrogen oxides should be regulated to reduce the formation of ground-level ozone. In addition to the Models-3/CMAQ system, emissions estimates generated by BEIS3 can be used in other air quality simulation models including EPA's Regional Acid Deposition Model.

ORD scientists also completed the Biogenic Emissions Landuse Database, which combines data on major vegetation species and land cover types in North America with emission data for 35 compounds. Both BEIS3 and the Biogenic

Emissions Landuse Database provide biogenic emissions data for use in air quality modeling simulations.



LOOKING TO THE FUTURE

Anticipated achievements in ORD's air quality research program include

- a report on personal exposure to, and indoor air concentrations of, particulate matter and gaseous pollutants for potentially sensitive individuals;
- a report on the cardiovascular effects of ambient particulate matter in healthy and susceptible humans and animals;
- predictive models for selected toxic compounds that quantify the relationships among exposure, dose, and the body's response;
- dose-response assessments for priority air toxics including benzene, 1,3-butadiene, cadmium, chloroform, and chloromethane; and
- characterization of fine particulate matter samples from priority sources such as pulp and paper mill operations and open burning.



Amount of biogenic emissions in regions of the United States characterized by different types of vegetation. Quantities are expressed as micrograms of carbon emitted per square meter per hour.

